CRUISE REPORT: Phase II of the shallow water acoustic experiments at the Atlantic Generating Station (AGS) Site

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1 INTRODUCTION

The three dimensional propagation and scattering of acoustic waves in shallow water regions is not very well understood. To better understand such processes, a simultaneous experimental and modeling approach needs to be considered. Accurate three dimensional environmental modeling in shallow water requires detailed knowledge concerning the properties of the sea bottom. Due to the cost, however, very few data sets with sufficient seafloor physical properties are presently available for proper field experimentation. One such region, shown in Figure 1, is located on the new Jersey Continental Shelf, near Atlanic City. The geology in this area is very well defined due to the many bottom cores that have previously been taken.[12,13] Figure 2 is a map of the site along with the locations of some of the cores, and Figure 3 is one cross section of the area as interpreted by Stahl et al.[1] using these cores and other information.

In the past few years, the ocean acoustics laboratory at the University of Delaware has been working on field experiments in this region to establish a test bed for a long term study of the area.[2,3] In particular, an acoustic experiment was conducted during the Summer of 1992 aiming to determine the azimuthal dependence of the acoustic wavefield in a bottom limited environment.[3]

This report summarizes the continuation of the experimental work with the addition of a more detailed environmental description during the period when the acoustic experiments were conducted. A three dimensional chirp sonar survey of the seabed down to a depth of 20 meters below the water-seabed interface was conducted by Florida Atlantic University and the University of Delaware prior to the acoustic experiments.[5] Subsequent acoustic experiments were conducted using both a continuous wave source and an airgun to address the relationship of the acoustic wavefield to the range and depth dependent seafloor properties as well as the temporal fluctuations in the water column.

This report is divided into 5 sections. The objectives of this most recent work at the AGS Site are discussed in Section 2. In Section 3, the experiments that were conducted are outlined. In Section 4 some preliminary data is presented, and in Section 5, a brief summary is given.

2 OBJECTIVES

The objectives of our acoustic experiments are:

1. **To conduct calibrated shallow water acoustic experiments aiming to better understand the spatial dispersion of acoustic waves in a geologically known region**

   From data collected in previous experiments conducted at the AGS Site, it was concluded that the acoustic wavefield dispersion is highly dependent on the azimuth.[3] This work suggested that the dependency may be attributed to several factors relating to topography, range, and sediment depth features. This experiment, similar to the previous experiment, has had improvements made in its design. These improvements include: (1) more accurate positioning through the use of the Differential Global Positioning System (DGPS), (2) source monitoring capability, (3) additional signals transmitted and received, as well as (4) a better three dimensional view of the geology provided by chirp and sidescan sonar surveys. It is hoped that the results of these experiments will reaffirm the previous conclusions, and also help in understanding what factors contribute to the azimuth dependency.

2. **To examine the frequency-range dependence of transmission loss (TL) and its relation to the environment**

   The data set resulting from the previous cruise had somewhat limited range sampling. The data from this cruise can be more useful for studying frequency-range dependent transmission loss, with several experiments specifically designed for this purpose.

3. **To provide a data set for calibration and verification of inverse techniques against a ground truth**

   The AGS Site is unique in that there is a great deal already known about the sea bottom. This work at the AGS Site has resulted in a second detailed and well sampled acoustic data set, and chirp and sidescan sonar surveys have added to the already extensive knowledge about the geology in this area. In addition, detailed environmental information was recorded during the experiment including: CTD data (Conductivity, Temperature, Density), ADCP data (Acoustic Doppler Current Profiler), and wind speed. This makes it an ideal data set for testing and verifying both existing and future inverse techniques.

4. **To provide a test bed for three dimensional propagation and scattering experiments in the future**

   By incorporating the previously collected core data with new information from chirp and sidescan sonar surveys, we can essentially reconstruct the three dimensional bottom/subbottom structure of this region. With broadband and continuous wave (CW) acoustic sources utilized in different experimental configurations, this area can provide a test bed for three dimensional propagation and scattering model/data comparisons. The data set collected in 1992 is being considered for such three dimensional analysis at present.[4]

5. **To examine the effects of oceanographic temporal variability on acoustic wave propagation**

   Small scale ocean variabilities can effect the acoustic wave propagation at different frequencies. One of the objectives of this latest work is to examine this effect in a carefully conducted experiment. This is done by meticulously monitoring oceanographic environmental parameters for the duration of each acoustics experiment.

Recently, some experiments have been conducted in this area by several investigators such as Rutgers University and Woods Hole Oceanographic Institute.[8] The site is referred to as LEO-15 by these investigators, and the focus of these experiments has been environmental characteristics of the sediment transport, in addition to biological studies.

3 EXPERIMENTS

The actual experiments conducted at the AGS Site during May, 1994 were a carefully designed amalgamation of many different systems and equipment. The main platform from which surveys and experiments were conducted was the Univeristy of Delaware's *R/V Cape Henlopen.* For acoustics experiments, the University of Maryland's *R/V Aquarius* was used as a means for carrying the source.

3.1 Surveys

Two surveys were conducted in conjunction with the acoustics experiments at the AGS Site. A chirp sonar survey was carried out approximately two weeks before the acoustics experiments by Florida Atlantic University and the University of Delaware Ocean Acoustics Laboratory, and a sidescan sonar survey was conducted by the United States Geological Survey at Woods Hole during the same cruise that the acoustics experiments were carried out. The results of these surveys are expected to greatly enhance our geological data of this area.

3.1.1 Chirp sonar

Chirp sonar is a towed, frequency modulated, sub-bottom profiler which can produce high resolution images of ocean sediments. Most useful is the fact that the high quality reflection data can be used for generating maps of sediment materials and physical properties such as grain size, density, and porosity.

From May 5, 1994 to May 12, 1994, a chirp sonar survey of the AGS Site was conducted.[5] The survey involved towing the chirp sonar fish over a series of predetermined grids, such as the one shown in Figure 4. The data collected as a result of this survey comes in the form of cross section images which are a very useful tool for evaluating the layering structure in the area. Figure 5 is an example of an image generated from a typical transect, which in this case tends West to East.

3.1.2 Sidescan sonar

Sidescan sonar is a towed system that is capable of accurately classifying surficial bottom properites. The acoustic image received by the system is a combination of parameters including seafloor bathymetry, micro-relief, sediment texture, sediment composition, and sediment compaction. Like the chirp sonar system, the sidescan fish is usually towed over a set grid. This grid is determined based on the range setting of the side looking sonar. Upon completion of the data collection, the data is plotted in a contour fashion and interpolated into a "mosaic" which gives a very useful picture of the bathymetry of the area, along with some information on the properties of the surficial bottom sediments.

An initial survey of the area around the AGS Site was completed during June 10-14, 1991 by the U.S. Geological Survey.[6] A continuation of this work was carried out during this most recent cruise. The bulk of the actual profiling was completed at night after the airgun and M-Sequence work was ceased for the day. In this survey, the sidescan system was set to insonify the seafloor to 100 m to each side of the towed vehicle, and a grid was established with 150 m line spacing. This allowed for a complete resurveying of the 3 by 7 km area originally surveyed in 1991.

Initial examination of the newest data indicates that the area has changed since the 1991 survey.[7] Some of these changes include, (1) high-backscatter patches are now rippled, (2) mounds of surf clam shells on the seaward side of the sand ridge have been dispersed, (3) high-backscatter patches shoreward of the sand ridge have changed orientation from approximately NE-SW to NW-SE, and (4) the seaward limit of these high-backscatter patches has moved about 100 m seaward of where it was in the 1991 survey.

3.2 Acoustic experiments

The acoustic experiments conducted during this cruise consisted of a series of carefully designed investigations using the broadband airgun source, as well as a programmable continuous wave (CW) source which transmitted "M-Sequences". Figure 6 is a diagram of the general configuration used in the airgun experiments.

3.2.1 Matched field processing

An attempt has been made to collect accurate acoustic and environmental data at a geologically known location, for the purpose of matched field processing (MFP) analysis in very shallow water. Two different experimental configurations were designed. Figures 7 and 8 show the postions of the source and receiver ships as deployed at the site for these two experiments. High resolution seafloor properties, topography as well as source and received acoustic signals exist for each experiment. The positions of source and receivers are accurately measured in the vertical and horizontal planes. It is anticipated that this data set will be used for shallow water MFP analysis.

3.2.2 Sediment variability effect on the broadband acoustic wave propagation

The AGS Site is composed of two regions with distinctly different surficial geology structure, which makes it an ideal area for studying the effect of sediment variability on broadband acoustic wave propagation. Accordingly, an experiment was designed that had sampling in the different geologic areas. The configuration for this test is shown in Figure 9, showing the points where shots were fired. The groups of points that make up the western most leg were all fired from the West side of the AGS

Site, which has distinctly different geology than the East side, where all the shots that make up the eastern most leg were fired from. The points that make up the middle leg depict shots which were essentially fired on the boundary between the two regions.

3.2.3 Transmission loss versus range

One of the objectives of this cruise was to provide data useful for studies of frequency-range dependent transmission loss. For this purpose, an experiment was specifically designed that had good sampling in range. Figure 10 shows how the source ship slowly moved away from, and then towards, the receiver ship while airgun shots were continuously fired. Transmission loss is calculated easily by comparing the signal from the source monitor hydrophone with that received at the array. The resulting data will be useful for studying frequency-range dependent transmission loss.

3.2.4 Effect of oceanographic temporal variability on acoustic waves

In an effort to thoroughly examine the role of temporal variability of oceanographic parameters on acoustic propagation, a fixed range experiment was conducted. The idea here was to maintain both the source ship, *R/V Aquarius*, and the receiver ship, *R/V Cape Henlopen*, at some range, transmit a series of shots as well as M-Sequences, while at the same time sampling oceanographic parameters at close time intervals. The source ship was positioned at 39° 28.3150' N 74° 15.3655' W while the receiver ship was anchored approxiamtely 218 meters away at 39° 28.40' N 74° 15.20' W during this experiment. The two ships were able to maintain a relatively fixed postion due to the fact that they were three-point-moored (ie. held in place using three anchors).

Initial analysis of the CTD's taken during this experiment indicate that the oceanographic parameters do change significantly with time. (see Section 4.2) Comparing differences in the acoustic data with these results should provide some valuable insight into the effect of oceanographic temporal variability on acoustic propagation, especially with M-Sequences which promise to be highly sensitive to such changes.

3.2.4.a Generating Synthetic Pulses using M-Sequences

Narrow pulses are often used to obtain fine discrimination of arrival times along the various paths that a signal can travel. The signal/noise ratio at the receiver will be low because of the spreading of the signal energy over a time interval that encompasses all reflected and refracted signal paths. Stacking, or averaging, the results of multiple transmissions can raise the effective signal/noise ratio, but the pulses must be separated in time by an interval corresponding to the time required

for all significant signal paths to clear the receiver. This means that the efficiency of the source is limited to (pulse width)/(interpulse time) compared to the CW efficiency.

Maximal Length Sequences (M-Sequences) use number-theoretic binary pulse trains to encode (by convolution or phase shifting) pulse energy into a form that retains the required spatial resolution while delivering close to the maximum possible CW signal power to the signal. To use an M-Sequence, convolve the desired signal pulse with the M-Sequence, transmit the resulting signal, then perform a circular correlation of the received signal with the transmitted sequence. Since the circular correlation of an M-Sequence with itself is a pulse (delta-function) at the origin (t=0), the result will be the same at that obtained when correlating the original transmitted pulse with the received signal. In addition, the M-Sequences can be stacked in the same way as the original pulses, resulting in an even larger signal/noise ratio.

3.2.4.b Use of M-Sequences in the acoustics experiments

The pulses used in the acoustics experiment were gaussian envelopes modulated by a sinusoidal carrier. The carrier frequencies chosen were 600 Hz, and 1, 2, 3, 4, 5, 6, 7 kHz. The gaussian envelope was chosen to make the width of the processed received signal 1 millisecond wide at the 1/2 the peak amplitude. The pulses were convolved with an M-Sequence pulse train of length 511 spaced at intervals of 1 millisecond to give a total sequence length of 511 milliseconds. This length was used to guarantee that all arrival paths would have sufficient time to arrive at the receiver before the sequence repeated itself. To improve signal/noise, 43 of the sequences were transmitted repetitively and the middle 40 were averaged prior to circular convolution. The resulting processed signal had a 43 dB improvement in signal/noise ratio over the unprocessed signal.

To insure stability, both the transmitter (a J11-3 projector capable of producing a wide-band output of 167 dB re 1 micro Pascal @ 1 meter) and the receiver hydrophones were mounted on rigid mounts on the sea floor. The receiver hydrophones (F-42b hydrophones with sensitivities of -198 dB) were placed in a cross arrangement with the face of the cross normal to the incident energy from the transmitter. The separations of the hydrophones in the cross was 1 meter horizontal and vertical with the bottom hydrophone being 1 meter off the sea floor and top being 3 meters off the sea floor. The projector was mounted 2 meters off the sea floor. The distance from the source to the receiver cross was about 200 meters. The tripod mount assemblies for the source and receiver units are shown in Figure 11.

The M-Sequences were transmitted continuously over a 4 hour period. A single run consisted of a transmission of each of the above frequencies. For each transmission, the signals received at the 5 hydrophones of the cross were recorded by the Time Domain Acquisition System (TDAS) of NRL. The transmitted signal was also

captured at a monitor hydrophone (also an F-42b) 16 meters from the transmitter. The total number of runs was 11.

The experiments and surveys composing this cruise to the AGS Site are tabulated in Table 1. In addition, Appendix A contains a list of some the primary equipment employed during the cruise.

Table 1: Summary of experiments at the AGS Site during May, 1994.

Day	Activities
5 to 12 May	Conducted chirp sonar survey. (Fig. 4) Collected bathymetry data simultaneously. (Fig. 13)
26 May	Match-Field Processing (MFP) experiment (Fig. 7) Sidescan survey
27 May	Sediment variability experiment (Fig. 9) Sidescan survey
28 May	Airgun/M-Sequences with ocean temporal variability monitoring Sidescan survey
29 May	Fixed range M-Sequence transmissions. More range-dependent transmission loss Second MFP experiment (Fig. 8) Sidescan survey
30 May	Alternating airgun/M-Sequences at various ranges.

3.3 Environmental information

3.3.1 CTD data

CTD data (Conductivity, Temperature, Depth) was collected from both the *R/V Cape Henlopen* and the *R/V Aquarius.* The CTD casts were conducted periodically throughout the duration of each day of experiments. In this way, a true picture of the variation in oceanographic parameters with time is obtained.

In addition to temperature and depth measurements, various other ocean properties were automatically sampled by the two CTD instruments such as pressure, salinity, oxygen content etc. As an example of the raw data, Figure 12 shows sample CTD depth profiles taken on May 25 by the *R/V Henlopen.*

3.3.2 Bathymetry

From May 5 to May 12, 1994, as part of a chirp sonar survey, the *R/V Cape Henlopen* traversed a series of grids while the ship's on-board computer continuously recorded water depth, position and time. Concurrently, buoys deployed by researchers from Rutgers University recorded information on tidal cycles and amplitudes in the area.[8] In combining the information from the buoys and the chirp sonar data, the cyclic changes in height caused by tides can be used to correct the recorded depth soundings, and a very accurate 3-Dimensional bathymetric profile of the area can be constructed. Figure 13 shows a preliminary bathymetric map of an area of the AGS Site before tide correction.

3.3.3 ADCP and other information

The *R/V Cape Henlopen* was equipped with an Acoustic Doppler Current Pofiler (ADCP) which recorded data on the currents in the area. In addition, *R/V Cape Henlopen* on-board computers continuously recorded, among other things, wind speed and direction. This data, in conjunction with photographs of the sea surface taken throughout the duration of the experiment, can be used to accurately estimate wave heights.

4 COLLECTED DATA

4.1 Data post-processing

The conversion of shot signals from analog into the more manageable digital format was carried out using the A/D board. Because the A/D board has only 16 channels and at times the array consisted of 20 hydrophones, the digitization procedure had to be repeated twice. The board was set up to digitize recorder channels 1-10 and 15-20 the first time and channels 1-6 and 11-20 the second time. Then, by co-locating in time the common hydrophone signals, all the information for hydrophones 1-20 would be stored. The flow chart for digitizing the analog data and converting from binary to ASCII is shown in Figure 14 Figure 15 shows (a) the timeseries recorded from the source monitor hydrophone, and (b) a sample time series plots for shot number 600, hydrophones one through ten.

Also, processing was being carried out on the M-Sequence data. Samples of the processed received signal (11 runs starting at the bottom of the plot for the center of the cross) are shown in Figure 16, for 1 kHz, and Figure 17, for 5 kHz.

4.2 CTD data processing

In analyzing the CTD data, sound speed was calculated from an empirical equation[10] and some depth-sound speed profiles were plotted (Figure 18).

One important use for the CTD data is to assess variation in temporal oceanographic parameters. To accomplish this, the sound speed profiles were interpolated to various depths and the sound speed's variation with time at fixed points in the ocean studied. Having the data in this form is useful for testing of propagation models. In addition, when analyzing the M-Sequence data taken over the same timespan, the sound speed's variation with time becomes important in understanding some of the more pronounced signal characteristics. Figure 19 shows the variation of sound speed with time at a few selected depths.

5 SUMMARY

Shallow water acoustics experiments were successfully carried out from May 25 to May 30, 1994 at the Atlantic Generating Station (AGS) Site. A sidescan sonar survey was conducted during this same cruise, and a chirp sonar cruise was carried out from May 5 to May 12, 1994 to provide three dimensional bottom geoacoustic data. This report (1) summarized the objectives of this work, (2) discussed individual experiments and equipment used, and (3) presented some preliminary data. Initial observations indicate a very high quality data set with high correlation between the acoustic data and the environment.

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The personell who participated in these experiments at the AGS Site are listed here in alphabetical order, beneath their respective institutions.

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Appendix A - Equipment

A list of the primary equipment and their specifications:

1. Acoustic array - 20 element Teledyne "T-2" hydrophone array with preamplifier and quick release at 10 meters to be used in "very shallow" water depths.

2. Airgun - 20 cubic inch Halliburton Sleeve Gun.

3. Firing controller - Mitchum Industries radio, antenna, speaker boxes, encoder/decoder, source controller unit and interface to gun.

4. Analog recorder - Teac XR-7000, 21 channel analog FM recorder.

5. A/D board - United Electronics WIN-30, for converting anolog recorded shots to digital, in addition to real time digital aquisition.

6. Ranging system - Racal Micro-Fix two range system.

7. Continuous wave projector - J11-3 programmable projector, and accompanying bottom mount tripod.

8. Source monitor hydrophone - A single F42-A hydrophone deployed at close proximity to source.

9. "Cross" array - Cross shaped configuration of 5 F42-A hydrophones mounted on an iron bottom mount tripod.

10. Differential Global Positioning System (DGPS) - A Magnavox DGPS unit was installed on the *R/V Aquarius* for recording position data.

11. Conductivity, Temperature, Depth (CTD) profilers - The *R/V Cape Henlopen* was equipped with a Neil Brown CTD that was deployed via a large winch on the starboard side of the ship. The *R/V Aquarius* had on board a hand-held, Sea-Bird Electronics "Seacat" SBE 19-03.

12. Acoustic Doppler Current Profiler (ADCP) - The *R/V Cape Henlopen* was equipped with a RDI Inc. ADCP, which recorded data on the ocean current activity beneath the ship.

13. Chirp sonar system - FM, pulsed signals swept over the frequency range of 200 Hz to 30 kHz.

14. Sidescan sonar system - Klein, 100 kHz sidescan sonar and a QMIPS data logging system.

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